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A global bibliometric review of dating methods in fluvial geomorphology from 1984 to 2026

Ebubekir Karakoca

ebubekir.karakoca@bilecik.edu.tr

Bilecik Şeyh Edebali Üniversitesi

Fatih Işık

Gümüşhane University

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A global bibliometric review of dating methods in fluvial geomorphology from 1984 to 2026

Ebubekir Karakoca[a]* and Fatih Işık[b]

[a] Bilecik Şeyh Edebali University, Faculty of Humanities and Social Sciences, Department of Geography, Bilecik, Türkiye. Email: ebubekir.karakoca@bilecik.edu.tr. ORCID: https://orcid.org/0000-0002-6454-2082

[b] Gümüşhane University, Faculty of Letters, Department of Geography, Gümüşhane, Türkiye. Email: fatihtrbzon.61@gmail.com. ORCID: https://orcid.org/0000-0001-9507-5651

* Corresponding author: Ebubekir Karakoca; ebubekir.karakoca@bilecik.edu.tr

ABSTRACT

Fluvial terrace systems are widely recognized as vital natural archives that record climatic fluctuations and regional tectonic movements throughout the Quaternary period. Deciphering their geomorphological evolution and quantifying river incision rates are intrinsically linked to robust geochronological dating methods. This study provides a focused bibliometric synthesis of the intellectual structure and long-term methodological evolution of dating techniques used in fluvial geomorphology between 1984 and 2026. A total of 1,077 publications retrieved from the Web of Science Core Collection were analyzed using the R-based bibliometrix package and VOSviewer software. A random 216-record subset (20.06%) was manually checked for thematic relevance; 86.57% was classified as directly or secondarily relevant. This sample-based assessment is distinguished from full-corpus eligibility screening. The analysis integrates publication trends, co-citation networks, keyword co-occurrence mapping and thematic structure

evaluation. The results indicate a long-term expansion of the retrieved literature and prominent later-period representation of luminescence and cosmogenic terminology alongside continuing radiocarbon research. These patterns describe bibliographic visibility rather than universal replacement or superiority of dating methods. Synonym fragmentation, broad method labels and incomplete-year coverage limit interpretation of the original visualizations. While research output is concentrated in particular geographic hubs, countries including Türkiye and China are also represented in collaborative networks. Future research would benefit from integrating complementary dating strategies with high-resolution topographic data and numerical landscape evolution models.

Keywords: Fluvial geomorphology; River terrace; Optically stimulated luminescence dating; Cosmogenic nuclides; Bibliometric analysis.

1. Introduction

Fluvial systems are highly dynamic geomorphological environments that preserve sensitive records of Quaternary climatic fluctuations, base-level changes, and regional to local tectonic movements [1, 2, 3, 4]. The geomorphological evolution of these systems is primarily archived within river terrace staircases formed through repeated phases of aggradation and incision. These landforms constitute valuable natural archives preserving sedimentological, stratigraphic, hydrological, and geomorphological evidence of past environmental conditions and landscape evolution [5]. Consequently, establishing robust chronological frameworks for terrace formation and abandonment has become one of the fundamental challenges in quantitative fluvial geomorphology.

Recent advances in Geographic Information Systems (GIS), Remote Sensing (RS), high-resolution photogrammetry, and low-cost Unmanned Aerial Vehicles (UAVs) have significantly enhanced the spatial precision of topographic analyses. However, despite major improvements in terrain modelling and morphometric analyses, understanding the

timing, duration and rates of geomorphological processes fundamentally depends on reliable chronological control. The accurate determination of terrace ages constitutes a prerequisite for quantifying river incision rates, sediment accumulation phases, and regional tectonic uplift. In this respect, chronological frameworks should not be regarded merely as complementary tools, but rather as the methodological foundation of fluvial landscape reconstruction.

Over recent years, fluvial geochronology has undergone a major methodological transformation driven by advances in analytical dating techniques. Traditional chronological approaches, particularly radiocarbon dating, have progressively been supplemented by Optically Stimulated Luminescence (OSL) and Terrestrial Cosmogenic Nuclide (TCN; e.g., ^{10}Be, ^{26}Al) dating methods [6, 7, 8]. This transition has occurred not only because of technological innovation, but also due to the increasing need for dating techniques capable of resolving older fluvial archives, extending temporal coverage, and directly constraining the ages of sediments and erosional surfaces. OSL dating enables the determination of sediment burial ages by identifying the last exposure of mineral grains to sunlight, whereas cosmogenic nuclides quantify the duration of geomorphic surface exposure to cosmic rays, thereby constraining terrace abandonment ages. Together, these complementary methods have progressively shifted fluvial geomorphology from single-method chronological approaches toward multi-proxy dating frameworks, particularly in studies addressing river incision history, tectonic uplift, and long-term landscape evolution.

Despite the increasing importance of geochronological techniques in reconstructing fluvial systems, the intellectual and methodological evolution of these approaches has rarely been examined from a systematic and longitudinal perspective. Existing studies have primarily focused on establishing regional chronologies or addressing site-specific geomorphological problems, whereas the broader scientific transformation in dating

methodologies remains insufficiently synthesized. Although recent bibliometric studies have explored research trends in major river systems (e.g., [9]), their multidisciplinary scope often obscures the methodological evolution of numerical dating approaches and their implications for geomorphological interpretation.

A recent topic-modelling analysis of 30,397 geomorphology-related publications identified fluvial geomorphology among the extensively represented and increasing themes [10]. This broader disciplinary synthesis contextualizes the present focus on chronological methods. Existing reviews of fluvial archives and numerical dating already explain their geomorphological significance [11, 12, 13]; the present contribution concerns the bibliographic organization of that knowledge.

Accordingly, this study does not merely quantify publication outputs; rather, it seeks to clarify how methodological transitions in geochronology have transformed scientific understanding of river terrace systems and fluvial landscape evolution. By examining temporal publication trends, conceptual structures, collaborative research networks, and methodological transitions between 1984 and 2026, this study aims to reveal the intellectual development of chronological approaches underpinning modern interpretations of river terraces and landscape evolution. Using R-based bibliometric algorithms and network visualization tools, this research provides a transparent and reproducible framework for evaluating conceptual shifts, technological transitions, and global research dynamics in fluvial geochronology.

Furthermore, considering the growing application of OSL and cosmogenic dating techniques in Quaternary geology, tectonic geomorphology, and fluvial terrace studies in Türkiye, understanding the global methodological evolution of these approaches has become increasingly important. Therefore, this study also provides a methodological reference framework for future fluvial and tectonic geomorphology research conducted in Anatolia and comparable tectonic regions. By presenting a focused bibliometric synthesis

of geochronological dating methods applied to river terrace systems, this study contributes to identifying both the intellectual foundations and future research frontiers of fluvial geochronology.

2. Materials and Methods

2.1. Research Design and Data Retrieval

This study employs a quantitative bibliometric approach to evaluate the global scientific production and conceptual evolution of fluvial geomorphology in relation to advanced geochronological dating methods. Bibliometric analysis provides an objective, transparent, and reproducible framework for mapping the intellectual structure and thematic development of a research field [14, 15, 16, 17, 18].

The bibliographic dataset was retrieved from the Web of Science (WoS) Core Collection database. The archived records are predominantly indexed in the Science Citation Index Expanded (SCI-EXPANDED); six records do not carry this index label. Accordingly, the dataset is described as a WoS Core Collection corpus rather than an exclusively SCI/SCI-EXPANDED corpus. Index coverage influences the representation of research traditions and publication types but does not itself guarantee thematic relevance or methodological quality [19].

The search strategy was structured around two interdependent conceptual components: (i) fluvial geomorphology and landform descriptors, and (ii) geochronological dating techniques. The first component includes key geomorphological terms such as “fluvial geomorphology”, “river morphology”, “fluvial terrace”, and “river incision”, representing major fluvial processes and landforms. The second component incorporates widely used chronological tools, including optically stimulated luminescence (OSL), cosmogenic nuclide dating, radiocarbon dating (^{14}C), and radiometric techniques such as Ar/Ar and K/Ar methods.

A Topic-based Search (TS), which simultaneously scans titles, abstracts, author keywords, and Keywords Plus, was employed to provide broad initial coverage of relevant studies. The following expression reconstructs the search logic confirmed by the authors; a contemporaneous search-history screenshot was not retained:

TS = (("fluvial geomorphology" OR "river morphology*" OR "fluvial terrace*" OR "river terrace*" OR "river topography*" OR "alluvial*" OR "floodplain*" OR "channel evolution" OR "river incision") AND ("dating" OR "geochronology*" OR "OSL*" OR "optically stimulated luminescence*" OR "cosmogenic*" OR "radiocarbon" OR "14C" OR "Ar/Ar" OR "K/Ar" OR "TCN*" OR "radiometric dating" OR "terrace dating"))*

The search query was designed to retrieve studies at the intersection of fluvial geomorphology and geochronological dating. However, because broad topic-based searches may also capture partially related or ambiguous records, the retrieved corpus was subjected to an additional manual relevance validation procedure, as described below. The archived exports are dated 11 April 2026, yielding a total of 1,077 documents published between 1984 and 2026, including early-access articles. The first publication year in the retrieved archive is 1984; this should not be interpreted as the historical beginning of fluvial geochronology. A schematic overview of the methodological framework—including data collection, preprocessing, and bibliometric analysis—is presented in Figure 1. No document-type restriction was applied in the original descriptive analyses. The archive includes ten records dated 2026; complete-year series omit 2026, whereas archive-wide networks retain all 1,077 records. However, only English-language publications were considered to ensure consistency in data processing and thematic interpretation.

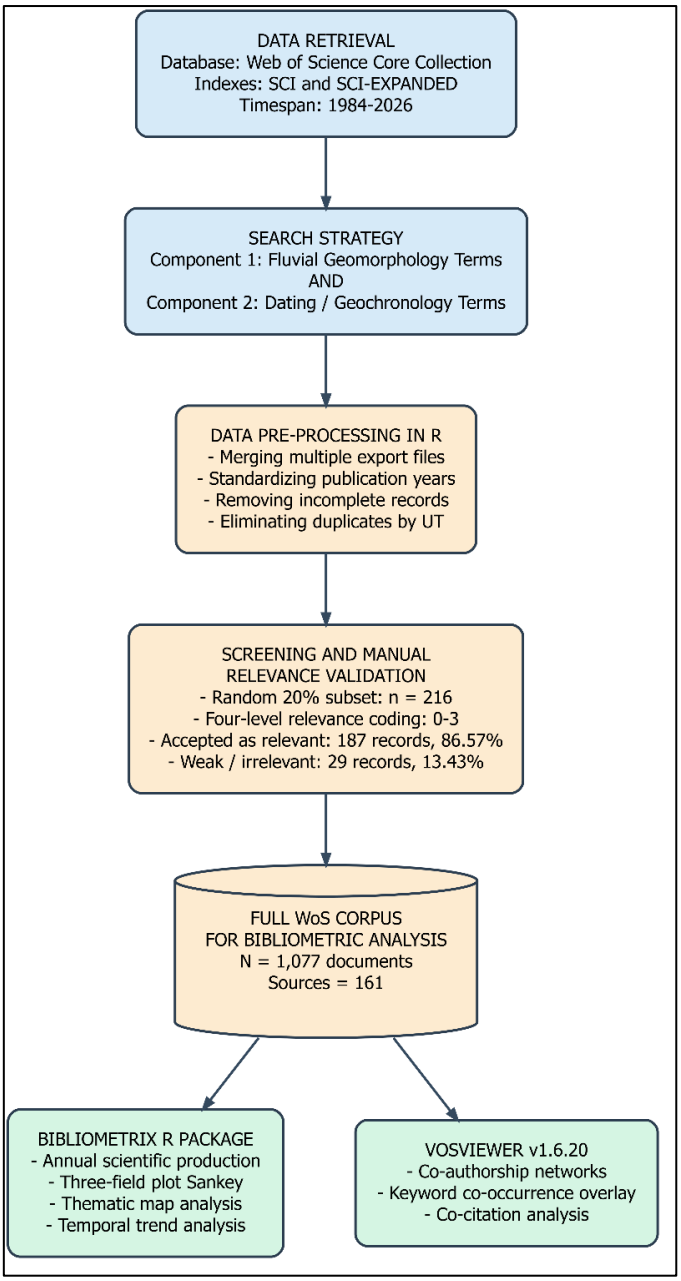

Fig. 1 Workflow of the bibliometric methodology used in this study, including Web of Science data retrieval, preprocessing in R, manual relevance validation of a random 20% subset, and subsequent analyses using bibliometrix and VOSviewer

Relevant reporting principles from PRISMA 2020 and PRISMA-S were applied retrospectively to describe the information source, search logic and record flow [20, 21]. Figure 1 links data preparation to sample validation and bibliometric synthesis. This is a bibliometric review with sample-based validation, not a claim of completed full-corpus systematic selection or prospective protocol registration.

2.2. Screening and Manual Relevance Validation

Because topic-based searches may retrieve records that contain broad fluvial terms such as “alluvial”, “floodplain”, or “dating” without necessarily focusing on fluvial geochronology, an additional manual relevance validation procedure was applied to assess the thematic reliability of the corpus. After merging the Web of Science export files and checking the WoS accession numbers, titles and publication years, the bibliographic corpus consisted of 1,077 documents. No duplicate accession number or missing title/year was detected. This screening step was designed to improve transparency in corpus construction, consistent with established principles for systematic literature assessment [22].

To evaluate the relevance of this corpus, a random validation subset corresponding to approximately 20% of the full dataset was selected in R (216/1,077 = 20.06%). This subset included 216 documents. The sampled records were manually checked by examining their titles and abstracts, with author keywords, Keywords Plus and bibliographic context used as supporting information. Automated relevance-priority labels were distinguished from these human decisions; independent duplicate assessment was not performed. The screening focused on two inclusion dimensions: (i) the presence of a fluvial geomorphological context, such as river terraces, fluvial terraces, floodplains, alluvial deposits, river incision, channel evolution, or drainage-basin evolution; and (ii) the explicit use or discussion of a geochronological or dating method, including radiocarbon dating, optically stimulated luminescence, cosmogenic nuclide dating, ESR, U-series, Ar/Ar, K/Ar, or related chronological approaches.

The validation subset was classified using a four-level relevance code: 3 = directly relevant, indicating that both fluvial geomorphology and geochronological dating were central to the study; 2 = relevant but secondary, indicating that both components were present but not necessarily the sole focus of the paper; 1 = weak or ambiguous relevance, indicating that only one of the two components was clearly present or that the relationship

to fluvial geochronology was indirect; and 0 = irrelevant, indicating that the record was outside the scope of fluvial geomorphology and geochronological dating.

The manual validation showed that 145 records were directly relevant and 42 were relevant but secondary, corresponding to 187 records, or 86.57% of the validation subset. In contrast, 13 records were classified as weak or ambiguous and 16 records as irrelevant, corresponding to 29 records, or 13.43% of the validation subset (Table 1). This validation step indicates that the search strategy captured a predominantly relevant bibliographic corpus while also identifying the degree of noise introduced by broad topic-based search terms. Records and terms identified as potentially ambiguous during this stage were considered when interpreting the bibliometric results, particularly keyword-based and thematic analyses.

The 216-record check was performed by one reviewer through title and abstract inspection; independent duplicate screening was not undertaken. The 86.57% proportion describes thematic relevance in this sample and does not certify every record in the 1,077-document corpus or measure search recall. Automated prescreening and subsequent human confirmation were treated as separate steps.

Table 1. Manual relevance validation results for the 20% random subset of the Web of Science corpus.

Relevance code	Meaning	Number	Percentage
3	Directly relevant	145	67.13%
2	Relevant but secondary	42	19.44%
1	Weak / ambiguous	13	6.02%
0	Irrelevant	16	7.41%
2 + 3	Accepted as relevant in validation subset	187	86.57%
0 + 1	Weak/ambiguous or irrelevant in validation subset	29	13.43%

2.3. Review protocol and PRISMA-informed reporting

A retrospective review protocol was documented to clarify the scope, information source, search logic, relevance assessment, and synthesis procedures. Relevant reporting items from PRISMA 2020 and its search-reporting extension, PRISMA-S, were used to improve methodological transparency [20, 21]. These guidelines were adapted to the bibliometric design; their use does not imply prospective protocol registration or a completed full-corpus systematic review.

The review focused on publications connecting fluvial landforms or processes with geochronological evidence. The search combined two conceptual groups: fluvial-context terms and dating-method terms. Terms within each group were linked using OR, and the two groups were combined using AND. The information source was the Web of Science Core Collection, and the archived exports were dated 11 April 2026. The search expression reported in Section 2.1 reconstructs the search logic used; a contemporaneous search-history record was not retained.

The three export files contained 500, 500, and 77 records, respectively. Records were checked for duplicate Web of Science accession numbers and missing titles or publication years. These checks identified no duplicate accession numbers or missing title/year values, leaving 1,077 records for the original bibliometric analyses. The archive covered 1984–2026. Because 2026 was incomplete at retrieval, complete-year publication trends were distinguished from analyses using the entire archive.

For thematic relevance assessment, a random sample of 216 records, representing 20.06% of the archive, was selected in R. Titles and abstracts were manually examined, with keyword and bibliographic information used as supporting context. Assessment considered whether each publication connected a fluvial landform or process with the application or substantive discussion of chronological evidence. The four-level coding

scheme distinguished directly relevant, secondarily relevant, weak or ambiguous, and irrelevant records. The confirmed classifications comprised 145, 42, 13, and 16 records, respectively. Consequently, 187 records (86.57%) were directly or secondarily relevant. Automated prescreening labels were distinguished from the subsequent manual assessment.

The manual assessment was performed by one reviewer; independent duplicate screening was not undertaken. The resulting proportion describes relevance within the sampled records rather than establishing eligibility of every publication or measuring search recall. No full-corpus full-text selection procedure is claimed. Figure 2 summarizes the relationship between retrieval, data preparation, sample validation, and bibliometric synthesis. Interpretation considers database and language coverage, broad search terms, keyword equivalence, and incomplete-year effects.

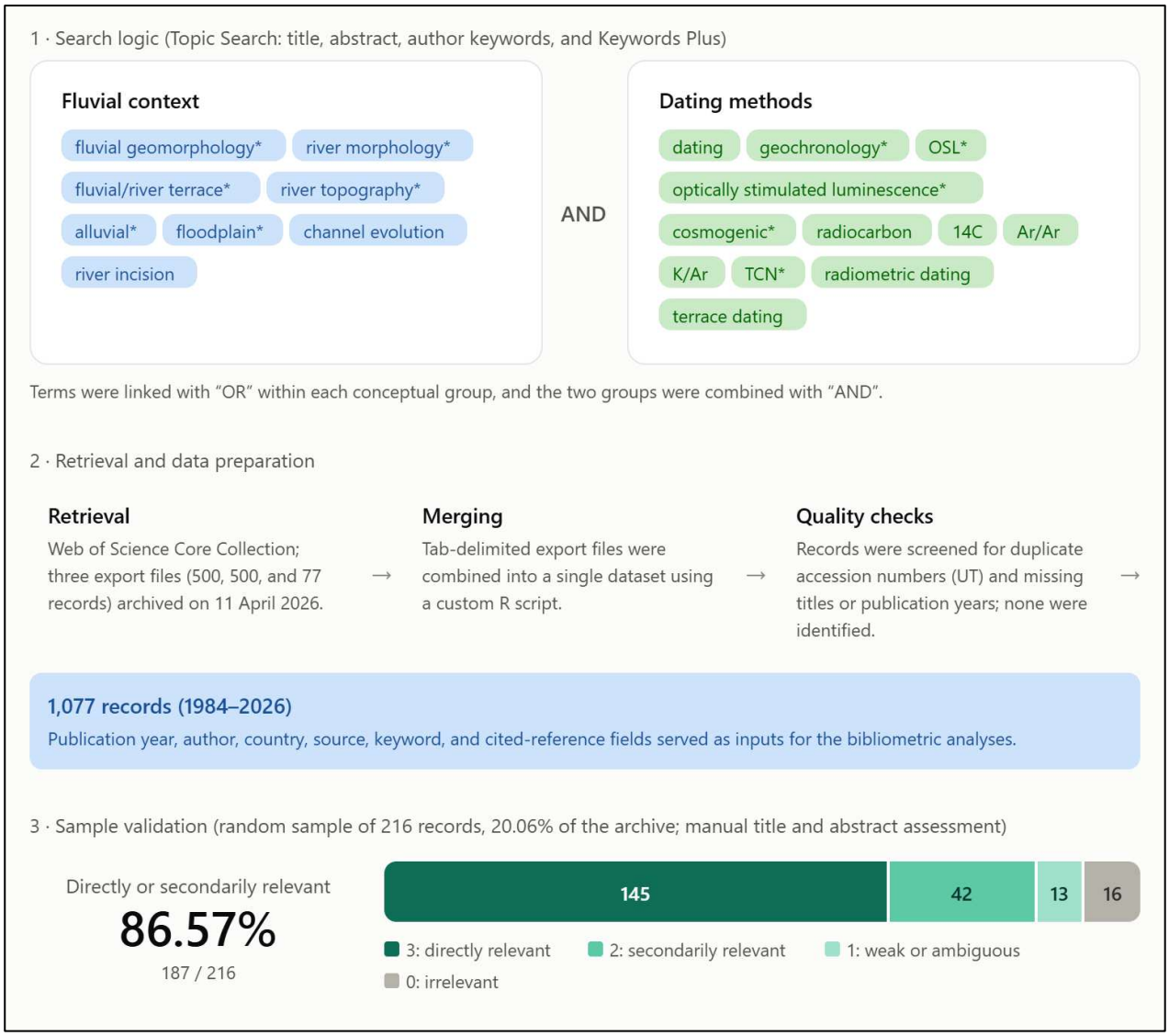

Fig. 2 Workflow of data retrieval, preparation, and sample-based relevance validation for the bibliometric analysis

2.4. Analytical Tools and Processing

To ensure a comprehensive, robust, and reproducible analysis, two complementary software tools were employed: the R-based Bibliometrix package and VOSviewer. Bibliometrix (R-package): The open-source Bibliometrix package (v4.2.2) was utilized for rigorous statistical analysis, encompassing annual scientific production, source impact, author productivity, and collaborative dynamics [23]. Given the inherent complexity of Web of Science tab-delimited export formats, a custom R script was developed to standardize and sanitize the raw data. This preprocessing pipeline included merging multiple

bibliographic files, normalizing publication years, filtering incomplete records, and performing de-duplication based on unique identifiers (UT). This step was critical to ensuring data integrity and research reproducibility. Furthermore, we employed the package's advanced functions to generate a Three-Field Plot (Sankey diagram) to visualize the structural flow between nations, thematic keywords, and journals, alongside a Thematic Map (based on Callon's algorithm) to assess the developmental maturity and centrality of key research themes.

VOSviewer: For network construction and topological visualization, VOSviewer (v1.6.20) was utilized. VOSviewer is a distance-based mapping tool specifically designed for constructing and visualizing bibliometric networks [24]. The software was used to generate:

- Co-authorship networks to identify patterns of international scientific collaboration,
- Keyword co-occurrence maps to reveal conceptual structures and research hotspots,
- Overlay visualizations to track the temporal evolution of research themes, particularly the transition from traditional dating techniques to advanced geochronological methods,
- Co-citation networks of cited references to identify the foundational literature (intellectual base) and primary methodological schools of thought underpinning the field.

The integration of these two complementary tools enables a multi-dimensional assessment, combining quantitative statistical evaluation with a nuanced visual interpretation of the scientific landscape.

Use of artificial intelligence: During the preparation of this manuscript, the authors used ChatGPT to assist with debugging the analysis code and improving the English language

and readability of the text. The authors reviewed and verified all AI-assisted changes and take full responsibility for the analyses, interpretations, and final content of the manuscript.

Terminology requires particular care: OSL and its spelled-out form are equivalent, whereas generic luminescence dating is broader and should not automatically be equated with OSL. Likewise, surface exposure dating alone does not establish cosmogenic methodology. The retained original keyword maps and three-field plot contain separate spelling variants; their nodes are therefore interpreted descriptively, without assigning distinct scientific meaning to synonymous terms. Keywords Plus also differs from author-supplied keywords. These limitations are considered in the interpretation rather than represented as already corrected in the original figures.

2.5. Dataset Characteristics

The bibliometric analyses were conducted on the full retrieved corpus of 1,077 WoS records, while the manually checked subset was used to assess sample-level thematic relevance. The corpus contains 45,055 cited references and has an average document age of 11.4 years. The reported co-authorship index is 5.62. These descriptive indicators characterize the retrieved literature; they do not independently establish research quality, interdisciplinarity or the balance between foundational and recent contributions.

3. Results

3.1. Temporal Evolution of Research

The 1,077-document archive covers 1984–2026, while Figure 3 shows annual publication counts through 2025. The series indicates a long-term increase with substantial year-to-year variation. As illustrated in Figure 3, scientific production was relatively stagnant until the late 1990s. An increase is observed after 2000, coinciding with the standardization of Optically Stimulated Luminescence (OSL) and Terrestrial Cosmogenic Nuclide (TCN)

dating techniques. Production peaked in the early 2020s, consistent with the increasing bibliographic visibility of chronological approaches in fluvial landscape studies.

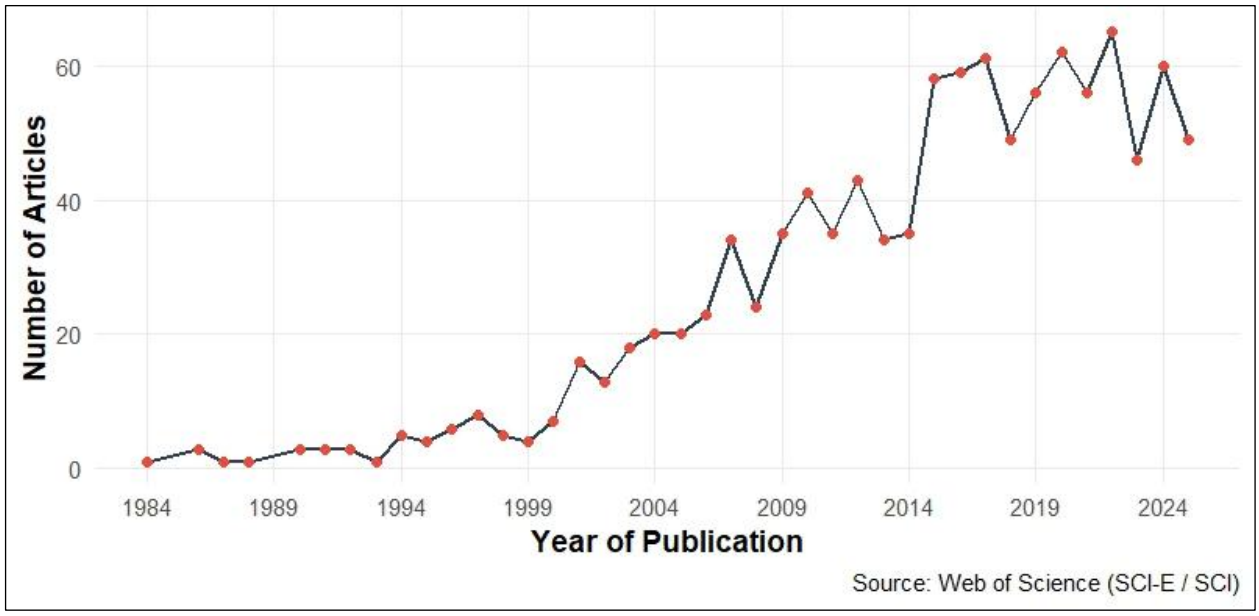

Fig. 3 Annual scientific production trends in fluvial geomorphology and geochronology research from 1984 to 2025. The embedded total of 1,077 refers to the full archive, including ten 2026 records omitted from this complete-year curve; 1,067 archived records are dated 1984–2025

3.2. Geographical Production and Citation Patterns

The geographical analysis (Figure 4a) shows a heavy concentration of research in the USA, which leads the field by a significant margin. The United Kingdom, Australia, and New Zealand also appear as major hubs, likely due to their long-standing tradition in quantitative geomorphology and advanced laboratory infrastructures.

Despite the recent surge in publication numbers, the mean total citations per document grouped by publication year (Figure 4b) reveals that the highest-impact studies were published during specific windows, notably in the early 1990s and mid-2000s. These peaks identify highly cited publication-year cohorts; attribution to specific methodological innovations requires article-level inspection. The recent decline in mean citations is a

standard bibliometric phenomenon (citation lag), as newer papers require more time to accumulate citations.

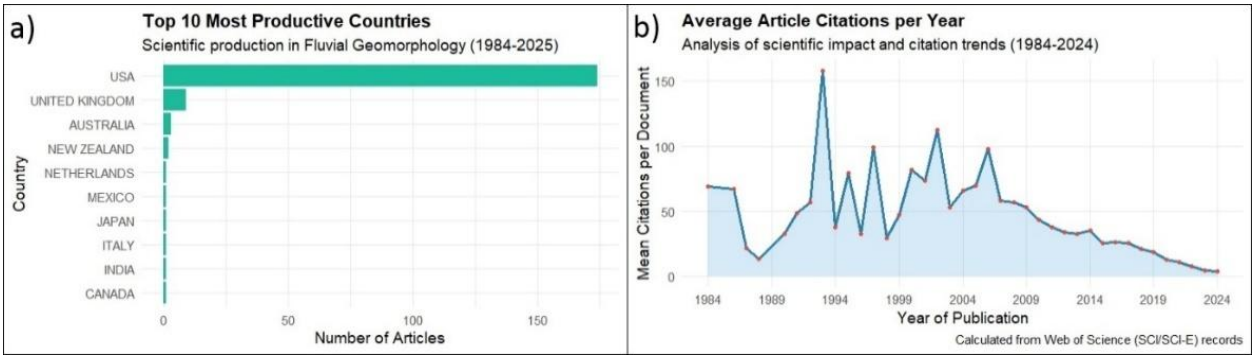

Fig. 4 Global research landscape and scientific impact: (a) Top 10 most productive countries and (b) Mean total citations per document grouped by publication year (1984–2024). Panel (b) does not normalize each document's citations by exposure time; its embedded heading should be read in conjunction with this definition

3.3. Conceptual Structure and Keyword Evolution

The keyword co-occurrence network (Figure 5a) reveals the intellectual backbone of the field, organized into four primary thematic clusters. The blue cluster represents the methodological core, where "fluvial terraces" and "OSL dating" exhibit the strongest link strength. The green cluster reflects the process-oriented research, linking "climate change" with "river incision" and "active tectonics." The presence of quantitative terms like "slip rate" and "incision rate" within this cluster signifies a transition from descriptive geomorphology to numerical landscape evolution modelling.

The yellow/light-blue cluster highlights regional tectonic archives, with "Türkiye" emerging as a prominent node closely associated with "uplift," "Quaternary," and "neotectonics." The red cluster signifies the massive scale of research on the "Tibetan Plateau" and the "Yellow River," where "ESR dating" and "loess" sequences are frequently integrated.

The overlay visualization (Figure 5b) shows differences in the average publication years associated with keyword occurrences. Older, established terms such as "Holocene" and

"radiocarbon dating" (in dark blue) are represented alongside more recently associated terms such as "cosmogenic nuclides," "incision rate," and "OSL dating" (in yellow/green). This pattern is compatible with increasing attention to high-resolution, long-term (Pleistocene) chronological frameworks in the retrieved literature. Overlay colours do not establish replacement of methods or causal process changes.

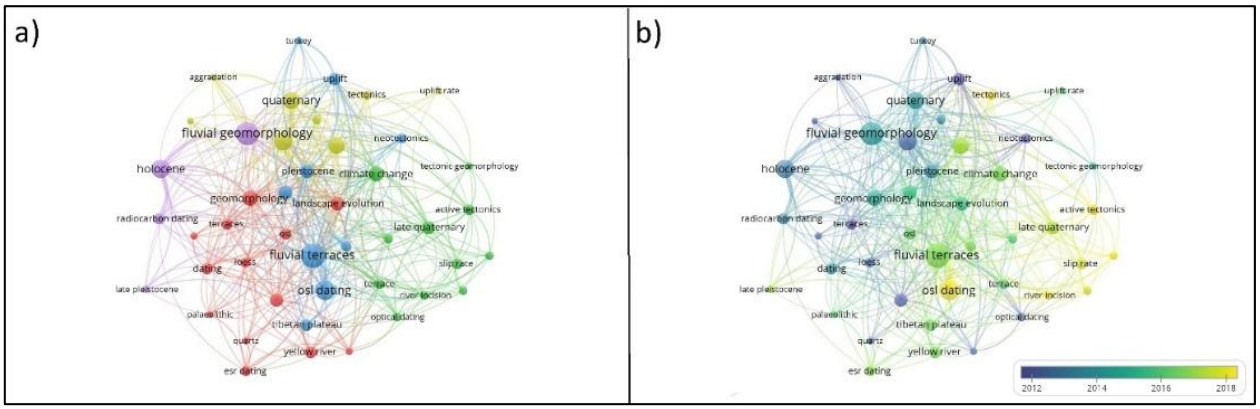

Fig. 5 Conceptual mapping of the field: (a) author-keyword co-occurrence network and (b) overlay visualization showing the average publication year associated with keyword occurrences; colours describe relative timing within the retrieved corpus

3.4. Global Collaboration Networks and Territorial Participation

The international collaboration landscape (Figure 6a) is characterized by a high degree of connectivity, dominated by a few major global hubs. The USA and Peoples R China stand out as the most central nodes, exhibiting the densest network of intercontinental links. The strong connection between China and the USA/UK primarily focuses on the geodynamic evolution of the Himalayan-Tibetan orogen, reflecting the global significance of this region as a climatic and tectonic driver.

England, Germany, and France form a robust European cluster, showing deep-seated collaborative traditions in Alpine and Mediterranean fluvial studies. Interestingly, the temporal analysis of country participation (Figure 6b) reveals an important shift in the field's sociology. While the USA and Western European nations (in dark blue) established the

foundational literature, nations like China, Türkiye, Brazil, and Iran (in yellow/bright green) are associated with comparatively recent publications in this network in the last decade. Specifically, the emergence of Türkiye as a bridge between European and Asian research networks is consistent with the importance of the Anatolian plateau as a key laboratory for understanding fluvial response to rapid continental uplift and climatic variability.

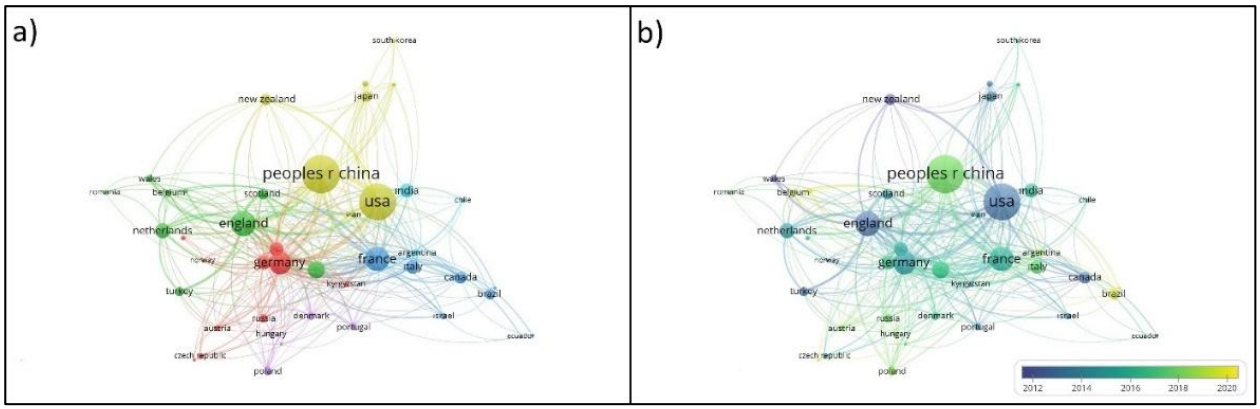

Fig. 6 International collaboration: (a) country co-authorship network and (b) overlay visualization of average publication year associated with country participation

3.5. Intellectual Base and Co-citation Network

To understand the foundational literature that underpins current research, a co-citation analysis of the 45,055 references was conducted. The resulting network (Figure 7) maps the intellectual base of fluvial geochronology into four distinct and highly specialized schools of thought.

The Luminescence Protocol School (Green Cluster): This cluster represents the methodological revolution in dating fluvial sediments. It is heavily dominated by the seminal works of Wintle and Murray [25] and Wintle and Murray [26], which discuss quartz OSL characteristics and methodological protocols relevant to single-aliquot regenerative-dose (SAR) applications. The prominence of Prescott and Hutton [27] within this group highlights the critical importance of cosmic ray dose rate calculations in luminescence geochronology.

The Cosmogenic Nuclide and Incision School (Blue Cluster): Located on the opposite side of the network, this cluster forms the foundation for quantitative erosion and exposure dating. It is anchored by theoretical and review papers such as Lal [28] and Gosse and Phillips [7], which provided the scaling factors and production rates essential for Terrestrial Cosmogenic Nuclide (TCN) applications. The strong link between this cluster and Anderson et al. [29] highlights the importance of explicitly accounting for inherited cosmogenic nuclide concentrations when dating depositional surfaces using in situ 10Be and 26Al.

The Fluvial System and Climate School (Red Cluster): This cluster bridges the gap between dating and landscape interpretation. The large node of Bridgland [30] and Bridgland and Westaway [5] illustrates the foundational paradigm linking global river terrace sequences to Quaternary Milankovitch climatic cycles. The presence of Vandenberghe [31, 32] further solidifies this cluster's focus on the response of river systems to alternating glacial-interglacial climate forcing.

The Tectonic Geomorphology School (Purple/Yellow Clusters): Situated centrally and bridging the other clusters, these nodes represent the application of chronology to tectonic problems. Foundational papers like Tapponnier et al. [33] and a Molnar-labelled reference from 1994 indicate links to large-scale geodynamic themes, in the co-citation network. The 1994 node should not be conflated with the separate Molnar et al. [34] publication in the reference list.

The spatial arrangement of these clusters—with the luminescence (green) and cosmogenic (blue) schools on opposite ends, bridged by theoretical geomorphology (red and yellow)-demonstrates how modern fluvial studies must integrate distinct physical dating tools to solve broad climatic and tectonic questions.

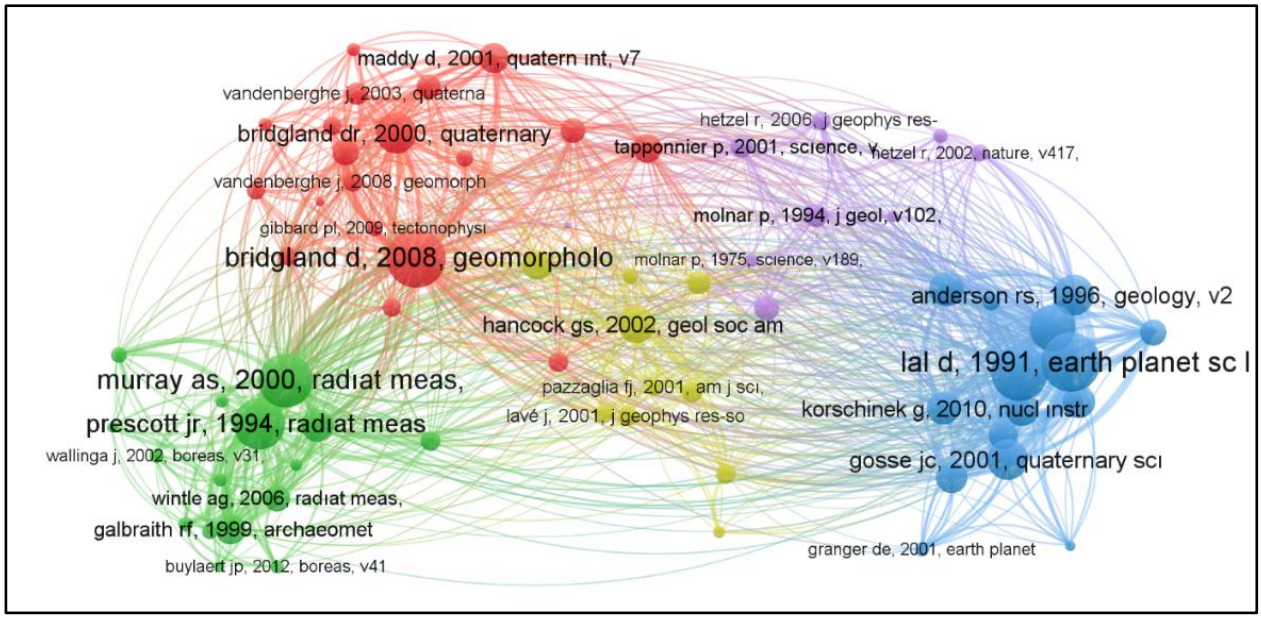

Fig. 7 Co-citation network of cited references. The size of the nodes indicates the number of co-citations, revealing the foundational publications (intellectual base) that shape the field of fluvial geochronology

3.6. Three-Field Plot Analysis: Structural Relationships

To systematically capture the scientific flow from producing nations through conceptual themes to dissemination platforms, a three-field plot (Sankey diagram) was generated (Figure 8). This analysis illustrates how specific national outputs are conceptually structured and distributed across high-impact journals within the field of fluvial geochronology.

The left sector (AU_CO) of the diagram highlights the geographic origin of the publications. In this specific configuration, the USA has the largest represented flow in the data flow, within the country field and selected nodes used here. The massive width of the USA's node demonstrates its deeply entrenched role in driving the global literature. While other nations such as India, the United Kingdom, and New Zealand are present in the network, their proportional representation is vastly overshadowed by the USA’s volumetric output. These selected flows describe this plot and should not be interpreted as an exhaustive country ranking or evidence of conceptual leadership.

The central sector (DE) reveals the core conceptual bridges linking these national outputs to the journals. The flow from the USA is highly diversified, channeling intensely into foundational geomorphological terms such as fluvial terraces and fluvial geomorphology. Crucially, methodological keywords, specifically OSL dating and luminescence dating, act as major transitional nodes. The presence of period-specific terms (Holocene, Pleistocene, Quaternary) alongside regional identifiers like the Yellow River highlights the field's dual focus on deciphering specific chronological epochs and analyzing large-scale regional fluvial systems.

The right sector (SO) represents the primary dissemination outlets. The conceptual flows converge predominantly into leading disciplinary journals. Geomorphology emerges as the ultimate and most capacious receptor for the broadest spectrum of topics particularly absorbing studies linked to fluvial terraces and OSL dating. Meanwhile, specialized Quaternary-focused journals-namely Quaternary Science Reviews, Quaternary International, and Quaternary Geochronology—form a robust secondary tier. These journals display thick, direct connections with explicit chronological concepts (Pleistocene, luminescence dating), reinforcing their specialized roles in publishing advanced dating applications and paleoenvironmental reconstructions.

Overall, the three-field plot links the represented country entries, keyword variants and publication outlets within the retrieved metadata. Because the diagram contains synonymous and spelling-variant keywords, their separate flows should not be interpreted as distinct scientific topics. The country field and selected-node configuration also limit comparisons with the country network in Figure 6.

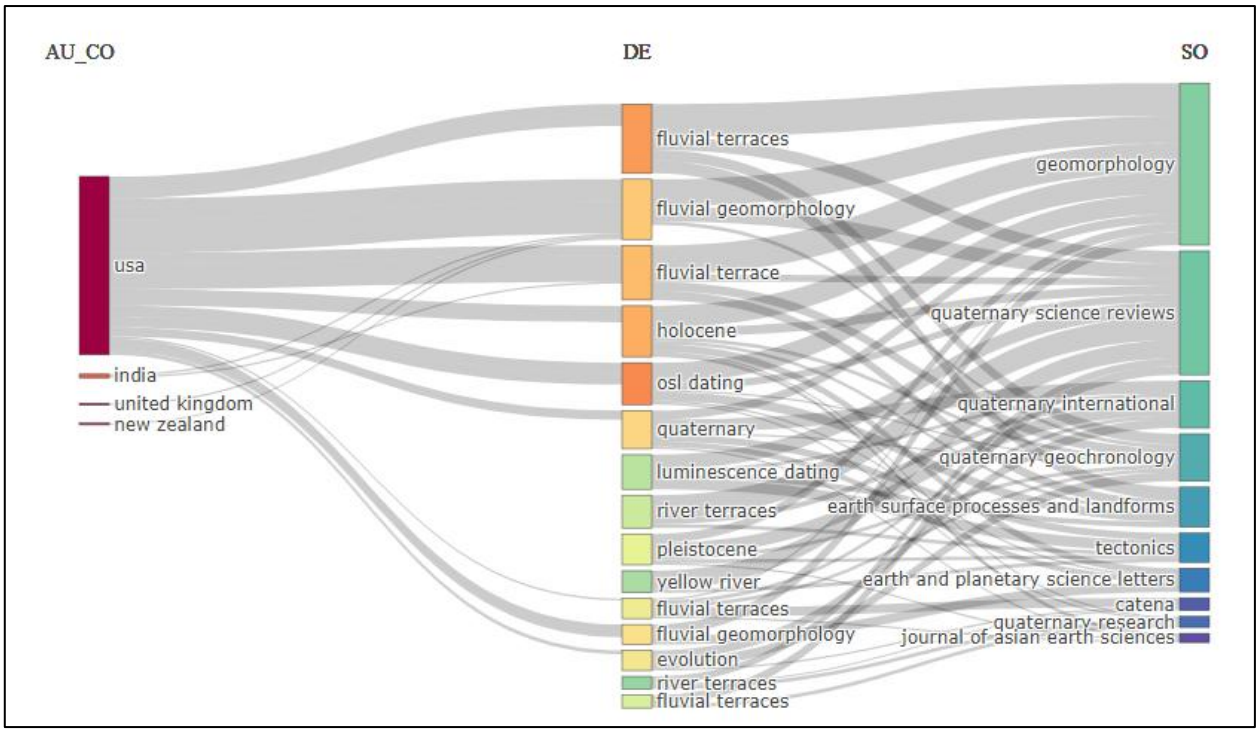

Fig. 8 Three-field plot (Sankey diagram) illustrating the scientific flow between producing countries (left: AU_CO), author keywords (center: DE), and publication journals (right: SO). The height of the nodes and the thickness of the flow lines reflect the proportional frequency and strength of connections within the literature

3.7. Thematic Map of the Conceptual Structure

To systematically evaluate the conceptual structure and developmental status of the literature, a thematic map analysis was conducted using co-word analysis and centrality–density framework [35] (Figure 9). This topological visualization categorizes research themes into four distinct quadrants based on two metrics: centrality (relevance degree, indicating the importance of a theme within the entire research network) and density (development degree, indicating the internal maturity and cohesion of the theme).

Motor Themes (Upper-Right Quadrant): Themes located in this quadrant are characterized by both high centrality and high density, meaning they are well-developed and essential to the structure of the research field. The prominent cluster comprising uplift, evolution, and climate is situated precisely at the border of this quadrant. This positioning suggests

462 that analysing the driving forces of landscape evolution—specifically tectonic uplift and
463 climatic fluctuations—is a prominent conceptual association of modern fluvial
464 geochronology. These themes drive the field forward, as accurately dating river terraces
465 is fundamentally aimed at resolving these broader geodynamic and paleoenvironmental
466 questions.

467 Basic and Transversal Themes (Lower-Right Quadrant): The lower-right quadrant contains
468 themes with high centrality but lower internal density, representing foundational concepts
469 that are crucial to the field but broad in application. The largest and most central cluster in
470 the entire network, consisting of fluvial terraces, OSL, and fluvial geomorphology, occupies
471 this space in the displayed map. This highlights that Optically Stimulated Luminescence
472 (OSL) dating and terrace morphology form the fundamental, transversal bedrock of the
473 literature. They are not isolated niche topics but rather the established baseline
474 methodologies and landforms represented in this keyword-based corpus.

475 Niche Themes (Upper-Left Quadrant): Themes in this quadrant have high density but low
476 centrality. The displayed cluster contains morphotectonics and the long-form keyword
477 optically stimulated luminescence dating. Because this term is synonymous with OSL, its
478 separation from the OSL cluster cannot establish an independent methodological school.
479 This position is treated as a descriptive feature of the original keyword representation,
480 subject to synonym and metadata effects.

481 Emerging or Declining Themes (Lower-Left Quadrant): The cluster containing alluvial
482 terraces and late Holocene has low centrality and density in the displayed map. A static
483 map cannot distinguish emergence from decline; therefore, no temporal decline of Late
484 Holocene studies is inferred from this position alone. Such a claim would require explicit
485 period-by-period analysis after keyword harmonization.

Overall, the thematic map provides a descriptive representation of keyword associations where OSL dating and terrace morphology serve as the foundational infrastructure (Basic Themes), while the quantitative resolution of tectonic uplift and climate change is represented among the high-centrality/high-density associations (Motor Themes).

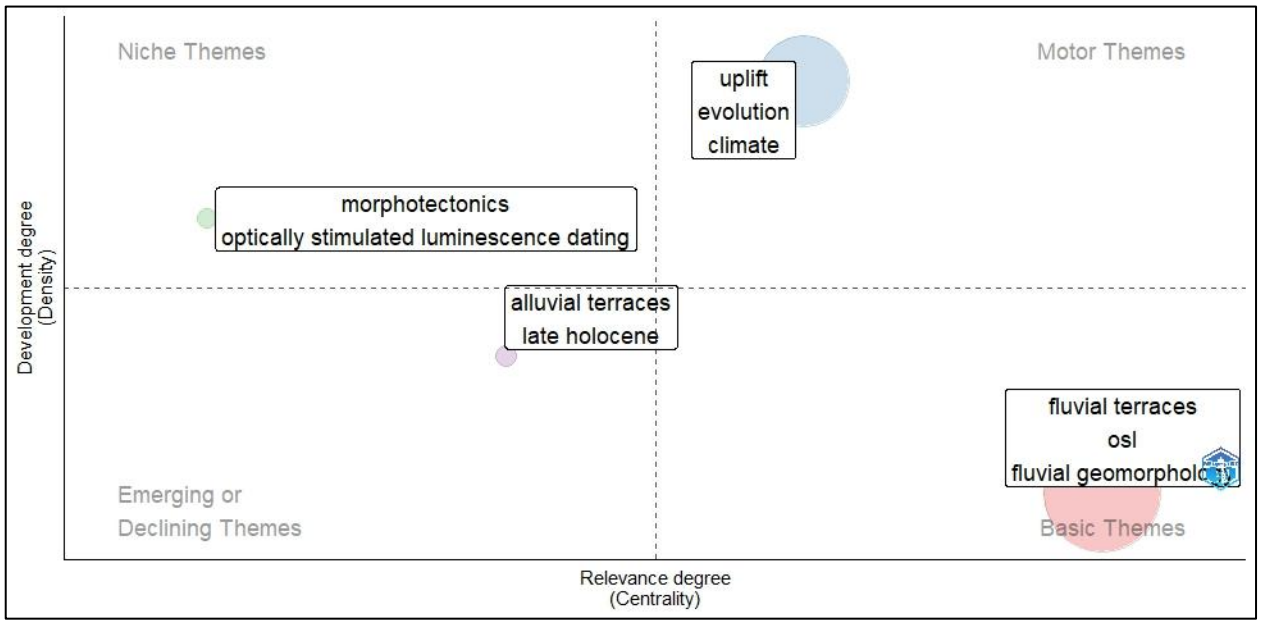

Fig. 9 Thematic map illustrating the conceptual structure of fluvial geochronology research based on Callon's centrality (relevance degree) and density (development degree) metrics. The size of the spheres is proportional to the occurrence frequency of the respective keyword clusters

3.8. Temporal Trends of Key Dating Technologies

To describe the bibliographic representation of methods within fluvial geomorphology, the temporal evolution of specific dating technologies was examined based on their annual publication frequencies (Figure 10). These are document-level mentions in the original metadata-based analysis, not independently verified laboratory applications or evidence of a fitted growth law.

Radiocarbon: In the early phase of the study period (1984–1999), Radiocarbon (14C) dating appears as the primary, albeit low-frequency, chronological tool. While its usage exhibits a steady presence throughout the entire study period, its frequency fluctuates after 2010. The curve alone does not explain these fluctuations. Radiocarbon applications depend on suitable carbon-bearing material, depositional association and the applicable chronological range.

Luminescence/OSL Terminology: The most striking feature of the temporal analysis is the greater later-period frequency of Optically Stimulated Luminescence (OSL). The curve becomes more prominent in the later part of the series; no exact crossover year or historical first application is inferred. The series shows marked peaks particularly between 2015 and 2023 (reaching nearly 40 publications annually). The original pattern dictionary also matches generic “luminescence dating”; therefore, this curve is not an exclusively OSL-specific indicator. The greater frequency indicates bibliographic visibility under that classification, not universal methodological superiority.

Cosmogenic Terminology: Running parallel to, but slightly below OSL, Cosmogenic nuclide dating has a prominent later-period representation. The series varies over time and does not demonstrate continuous growth. These methods provide a capability to date erosional features (e.g., strath terraces and bedrock gorges) and calculate river incision rates, providing a crucial complementary tool to the deposition-focused OSL method.

Niche Applications (Ar/Ar and K/Ar): In stark contrast to the luminescence and cosmogenic trends, Ar/Ar and K/Ar dating techniques maintain a flat, near-zero frequency throughout the entire 40-year period. Their low frequency suggests that radiometric dating of this type remains a highly niche application in fluvial geomorphology, particularly relevant in specific geological settings where river terraces are interbedded with volcanic deposits (e.g., basalts or tephra layers).

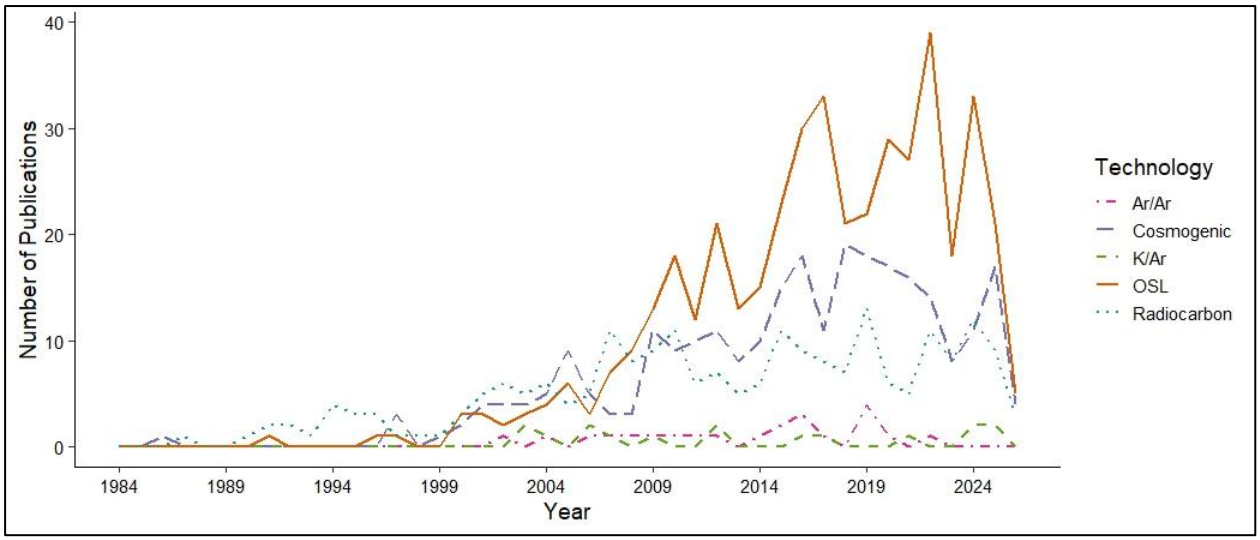

Fig. 10 Temporal trends of dating-method terminology in the original metadata analysis. The archive extends to 2026, and the terminal low count corresponds to the incomplete 2026 publication year rather than 2025. The luminescence/OSL category includes generic luminescence terminology, and multiple method categories may occur in a document. Curves are descriptive; no exponential-growth or method-replacement model was fitted

3.9. Temporal Trend Topics Analysis

To examine the evolution of research priorities, a trend topic analysis was performed based on the annual frequency of the most influential keywords (Figure 11). This analysis provides a longitudinal perspective on how the conceptual focus of the field has shifted over the last three decades.

The results indicate that foundational terms such as *fluvial geomorphology, fluvial terraces,* and *quaternary* have maintained a high and consistent frequency throughout the study period, establishing them as the perennial pillars of the field. However, distinct temporal trajectories are evident for specific dating and process-oriented topics.

The appearance of OSL in the literature exhibits a steady intensification, becoming a dominant "high-frequency" topic after 2010. Similarly, cosmogenic nuclides show a growing presence in the last decade, reflecting the increasing integration of in-situ isotope

analysis in geochronological frameworks. Notably, process-oriented keywords like incision and active tectonics have gained momentum since 2015, signaling a research transition from purely descriptive geomorphology toward the quantification of landscape dynamics and active tectonic processes. Furthermore, the persistent frequency of climate change and uplift across the timeline underscores their status as the two primary, long-term drivers of fluvial evolution in the literature.

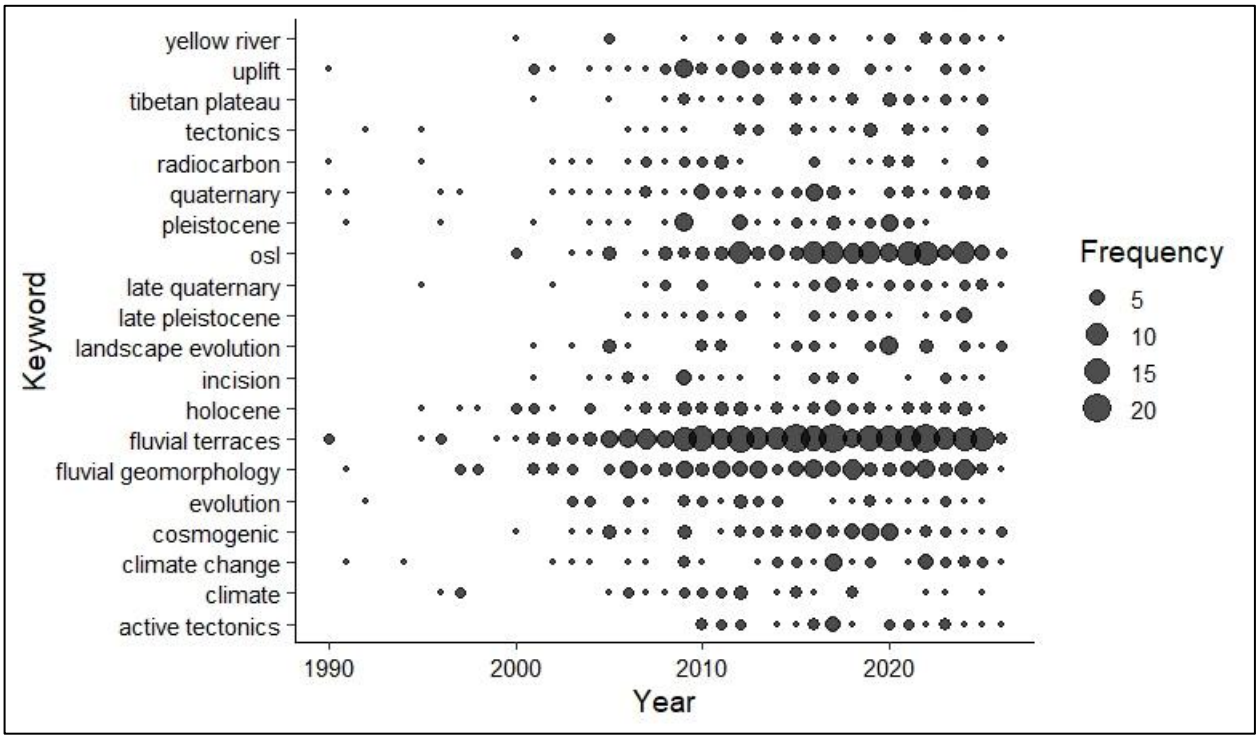

Fig. 11 Temporal trend topics in fluvial geomorphology and geochronology research. The bubble size represents the annual frequency of occurrences, illustrating the emergence, persistence, and dominance of key research themes over the past three decades

4. Discussion

4.1. Methodological Evolution

The bibliometric analysis of fluvial geomorphology literature over the past four decades indicates a substantial methodological transformation in the geochronological toolbox employed within the discipline [36]. Radiocarbon (14C) dating, which represented the dominant chronological approach during the earlier phase of research (1984–1999),

561 remains represented in the later literature, with year-to-year variation [37]. The publication
562 curve itself does not establish a causal explanation. Interpretation of this pattern should
563 consider the methodological constraints of the 14C method in fluvial environments-
564 particularly its restricted chronological range (~50 ka) and the often-limited preservation of
565 datable organic material in high-energy river systems characterized by frequent reworking
566 and sediment remobilization [38]. Consequently, while radiocarbon dating continues to
567 provide robust chronological control for Late Quaternary and Holocene fluvial deposits, its
568 applicability becomes increasingly constrained in studies targeting older terrace systems
569 and long-term landscape evolution.

570 In contrast, the prominent methodological transition identified in our longitudinal dataset is
571 the increasing prominence of Optically Stimulated Luminescence (OSL) and Terrestrial
572 Cosmogenic Nuclide (TCN) dating approaches. The growing prominence of OSL in later
573 publications appears to be closely associated with its ability to directly determine sediment
574 burial ages through the measurement of the last sunlight exposure of quartz and feldspar
575 grains, independent of organic material availability [39, 40, 12]. This methodological
576 advantage is particularly important in fluvial settings where suitable organic material is
577 frequently absent or redeposited. Furthermore, improvements in luminescence protocols,
578 increased analytical precision, and the development of approaches capable of extending
579 dating ranges beyond those achievable by radiocarbon methods have contributed to the
580 widespread adoption of OSL as one of the dominant chronological tools in river terrace
581 research. Simultaneously, the sustained increase in cosmogenic surface exposure dating
582 since the mid-2000s has introduced a crucial complementary dimension to fluvial
583 chronology. Unlike depositional dating techniques, TCN methods can constrain exposure,
584 burial or erosion under method-specific assumptions, thereby informing interpretation of
585 the abandonment ages of erosional landforms such as strath terraces, incised bedrock
586 surfaces, and fluvial gorges [8, 12]. This capability has significantly enhanced the

587 reconstruction of long-term river incision histories and tectonic uplift patterns, particularly
588 in actively deforming regions where quantifying landscape response to tectonic forcing
589 remains a central research objective.

590 The temporal overlay visualization further suggests a gradual conceptual transition within
591 the literature. Traditional terms frequently associated with Holocene chronologies and
592 radiocarbon-based approaches appear to have progressively given way to terminology
593 emphasizing longer temporal frameworks and quantitative geomorphological
594 reconstruction, including concepts such as “Pleistocene,” “cosmogenic nuclides,” and
595 “incision rate.” Likewise, the comparatively limited representation of traditional radiometric
596 methods (e.g., Ar/Ar and K/Ar) indicates that their application remains largely confined to
597 specific geological settings, particularly where fluvial terrace sequences are associated
598 with volcanic horizons. Taken together, these findings point to a broader methodological
599 transition from isolated, site-specific chronological approaches toward increasingly
600 integrated, multi-proxy frameworks capable of resolving complex tectonic and climatic
601 signals across broader spatial and temporal scales [12].

602 **4.2. Technological and Quantitative Integration**

603 Bibliometric findings suggest that fluvial geomorphology has undergone a notable
604 conceptual transformation over recent decades, gradually shifting from predominantly
605 descriptive field-based observations toward increasingly quantitative and process-oriented
606 analyses of landscape evolution [41]. The thematic convergence of concepts such as
607 'climate change,' 'river incision,' and 'active tectonics' with quantitative parameters
608 including 'slip rate' and 'incision rate' within the thematic network (green cluster) structure
609 may reflect this broader methodological transition. Furthermore, recent publication trends
610 are compatible with an emphasis on process-based investigations of 'active tectonics' and
611 'incision' dynamics, particularly after 2015 [5].

This transformation appears to be supported by the integration of high-precision geochronological methods, particularly OSL and TCN dating, high-resolution geomorphometric datasets derived from remote sensing technologies, including light detection and ranging (LiDAR) and digital elevation models (DEMs) [42, 43]. Within the conceptual structure analysis, the positioning of themes such as “uplift,” “evolution,” and “climate” within the Motor Themes quadrant suggests that these concepts increasingly occupy a central role in contemporary fluvial geomorphology research. This pattern may indicate that the objectives of modern fluvial studies have progressively expanded beyond traditional terrace mapping and chronological classification toward understanding the interactions among tectonic forcing, climatic variability, and long-term landscape evolution. In this regard, computer-assisted landscape evolution modelling and quantitative geomorphological simulations have emerged as increasingly important approaches for disentangling complex environmental signals.

Consequently, the integration of geochronological “time-slices” with high-resolution digital topographic “morphology” has contributed to the broader transformation of fluvial geomorphology from a primarily descriptive discipline into a more quantitative, interdisciplinary and process-oriented field [5].

4.3. Literature Gaps and Future Opportunities

The bibliometric analysis of geographical collaboration patterns and knowledge exchange indicates the continued prominent representation of the USA and Western Europe in shaping the intellectual foundation of fluvial geochronology in the retrieved metadata. The bibliometrix software reference [23] supports the analytical framework rather than a substantive geographical claim. However, temporal participation networks also suggest a gradual transformation in the geographical distribution of scientific production, characterized by the increasing international visibility of emerging research centres such as China, Türkiye, Brazil, and Iran. While China's massive scientific output is largely

638 concentrated on the Himalayan-Tibetan orogen system, Türkiye has increasingly gained
639 prominence as an important interface between European and Asian research networks.
640 Owing to its active neotectonic setting, the intersection of contrasting climatic zones, and
641 the presence of well-preserved fluvial systems (e.g., Kızılırmak, Euphrates, Tigris, Gediz,
642 Göksu, Filyos, and Sakarya; [3, 44]; [45, 46]; [47, 48]; [49, 50]; [51, 52]; [53, 54]; [55, 56];
643 [57, 58]; [59, 60]; [61, 62]; [63, 64]; [65, 66]; [67, 68]), Türkiye represents an important
644 natural laboratory for deciphering fluvial responses to rapid continental uplift and climatic
645 variability.

646 Historically, river terrace investigations in Türkiye relied predominantly on morphological
647 observations and relative chronological interpretations. However, over the last two
648 decades, the increasing application of OSL, cosmogenic nuclides, and K-Ar/Ar-Ar
649 geochronological approaches has substantially improved the analytical resolution and
650 chronological precision of fluvial studies [50, 44, 53, 68]. Rhodes [6] supports the OSL-
651 specific background, while Rixhon et al. [13] provides a broader synthesis of numerical
652 fluvial dating rather than sole support for Turkish argon-method applications. Despite these
653 advances, the integration of high-resolution cosmogenic isotope dating and
654 comprehensive multi-proxy chronological frameworks within tectonically active orogenic
655 settings remains comparatively limited relative to broader global trends. This limitation is
656 particularly relevant in regions characterized by complex interactions among tectonic
657 forcing, climatic variability, and river incision dynamics. A directly relevant Mediterranean
658 example is provided by Hubert-Ferrari et al. [63], who combined cosmogenic exposure
659 ages and radiocarbon constraints from Kızılırmak terraces to investigate deformation
660 along the central North Anatolian Fault and the Central Pontides. This illustrates
661 complementary chronological targets within a fluvial system rather than universal
662 replacement of one method by another.

Addressing this methodological gap may represent one of the most promising research directions for the coming decade. In particular, future progress is likely to benefit from the systematic expansion of multi-method approaches in which fluvial terraces chronologies based on OSL dating are integrated with in-situ cosmogenic surface exposure dating [69]. Such integration has the potential to improve chronological resolution by simultaneously constraining depositional ages and geomorphic surface abandonment histories. This approach may prove especially valuable in tectonically active regions such as Anatolia, Iran, and the Andean margins, where robust quantitative chronological frameworks remain insufficient for fully resolving the interactions between Quaternary tectonic activity and climatic oscillations [5, 70]. More broadly, reducing the current geographical and methodological concentration within the literature may contribute to a more globally representative understanding of fluvial landscape evolution. Expanding high-resolution chronological investigations across underrepresented tectonic and climatic regions would substantially enhance the capacity of the discipline to develop more comprehensive models of long-term river evolution and landscape response [11, 71].

4.4. Limitations of the Study

Several limitations should be considered when interpreting the findings of this study. First, the analysis is based exclusively on publications indexed in the Web of Science Core Collection and is restricted to English-language publications. Consequently, potentially relevant studies published in regional journals, books, conference proceedings, theses, technical reports, or non-English sources may be underrepresented. As a result, the dataset may not fully capture regionally significant research traditions or locally disseminated scientific contributions.

Second, although the topic-based search strategy was specifically designed to identify the intersection between fluvial geomorphology and geochronological dating methods, the inclusion of broad search terms such as “alluvial”, “floodplain”, and “dating” may have

introduced partially related or contextually ambiguous records into the dataset. To minimize this limitation, a randomly selected 20% subset of the corpus was manually validated, indicating that 86.57% of the evaluated records were directly or secondarily relevant to the study objectives. Nevertheless, this procedure should be interpreted as a corpus-level reliability assessment rather than a fully systematic screening of every individual publication included in the database.

Third, bibliometric indicators inherently depend on publication metadata, citation practices, author keywords, and indexing conventions. Therefore, such analyses cannot replace detailed field-based geomorphological investigations or laboratory-based geochronological assessments. Rather than providing direct evidence for geomorphological processes, the findings presented here should be interpreted as a quantitative synthesis of methodological preferences, conceptual trends, and collaboration patterns within the published literature.

Finally, because the dataset includes early-access publications up to 2026, recent publication trends and citation dynamics should be interpreted cautiously. The most recent years may be affected by indexing delays, incomplete citation accumulation, and citation-lag effects, which could influence the apparent representation of emerging methodological and thematic developments.

5. Conclusions

This study provides a comprehensive bibliometric synthesis of 1,077 documents published between 1984 and 2026, delineating the four-decade evolutionary trajectory of fluvial geomorphology and its geochronological foundation. The results document the bibliographic visibility of chronological tools and a long-term increase in publication output, without estimating a growth law or demonstrating a causal disciplinary transition.

The original descriptive analyses suggest changing thematic emphasis: while (14C) dating continues to be represented, Optically Stimulated Luminescence (OSL) has a prominent representation in the retrieved terminology for depositional sequences, and terrestrial cosmogenic nuclides (TCN) have become the critical complement for quantifying erosional incision. The thematic analysis is consistent with attention to quantitative landscape questions including 'incision rate' and 'tectonic uplift.'

Geographically, although research output remains concentrated in North American and Western European hubs, China and Türkiye are also represented in the collaborative literature. Türkiye's unique position, functioning as a vital natural laboratory at the intersection of diverse tectonic and climatic regimes, presents a relevant setting for future multi-proxy geochronological investigations.

We conclude that the future of fluvial geomorphology may benefit from the integration of three pillars: (i) multi-proxy dating (OSL/TCN synergy), (ii) high-resolution 3D topography (LiDAR/DEM), and (iii) numerical landscape evolution modeling. Advancing this integrated framework is a useful research direction for regions where tectonic forcing and climatic variability remain poorly constrained. By fostering cross-border collaboration and expanding high-resolution dating to less-studied orogenic belts, the community can construct a truly global, process-based understanding of fluvial systems in the Anthropocene.

Statements and Declarations

Previous conference presentation: This work was presented as an abstract-only conference contribution at the TÜCAUM 2026 International Geography Symposium on 7 October 2026 under the title "Evolution of Geochronological Dating Techniques in Fluvial Geomorphology: A Bibliometric Perspective (1984–2026)." No full-length conference paper was submitted or published.

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Author contributions: Ebubekir Karakoca: Writing – original draft; Writing – review and editing. Fatih Işık: Data curation; Formal analysis; Software; Visualization. The Web of Science search and R analyses were conducted as part of these contributions.

Data Availability Statement. The bibliographic records analysed in this review were retrieved from the Web of Science Core Collection on 11 April 2026. Access to the database requires a subscription, and redistribution of the exported records is subject to the provider's licence terms. The data supporting the findings of this review are available from the corresponding author upon reasonable request, subject to the provider's licence terms. The manual relevance classifications and analysis scripts are also available from the corresponding author upon reasonable request.

Ethics approval: Not applicable. This study analyses published bibliographic records and does not involve human participants or animals.

Consent to participate: Not applicable.

Consent for publication: Not applicable.

Clinical trial number: Not applicable.

References

1. Schumm S, Dumont J, Holbrook JM (2000) Active tectonics and alluvial rivers. Cambridge: Cambridge University Press.

2. Vandenberghe J (2002) The relation between climate and river processes, landforms and deposits during the Quaternary. Quaternary International, 91, 17–23. https://doi.org/10.1016/S1040-6182(01)00098-2

3. Westaway R, Pringle M, Yurtmen S, Demir T, Bridgland D, Rowbotham G et al (2003) Pliocene and Quaternary regional uplift in western Turkey revealed by long-term river

764 terrace sequences. Current Science, 84(8), 1090–1101.
765 http://www.jstor.org/stable/24107672

766 4. Lord M D, Germanoski D, Allmendinger N E (2009) Fluvial geomorphology: Monitoring
767 stream systems in response to a changing environment (in Young, R. & Norby, L.).
768 Geological Monitoring: Boulder, Colorado, The Geological Society of America, pp. 69-103.

769 5. Bridgland D, Westaway R (2008) Climatically controlled river terrace staircases, a
770 worldwide Quaternary phenomenon. Geomorphology, 98, 285-315.
771 https://doi.org/10.1016/j.geomorph.2006.12.032

772 6. Rhodes E J (2011) Optically Stimulated Luminescence dating of sediments over the
773 past 200,000 years. Annual Review of Earth and Planetary Sciences, 39: 461-488.
774 https://doi.org/10.1146/annurev-earth-040610-133425

775 7. Gosse JC, Phillips FM (2001) Terrestrial in situ cosmogenic nuclides: theory and
776 application. Quaternary Science Reviews, 20, 14, 1475-1560.
777 https://doi.org/10.1016/S0277-3791(00)00171-2

778 8. Ivy-Ochs S, Kober F (2008) Surface exposure dating with cosmogenic nuclides. E&G
779 Quaternary Science Journal, 57, 179. https://doi.org/10.3285/eg.57.1-2.7

780 9. Ma Y, Song T (2024) A bibliometric review and interdisciplinary analysis of the
781 Brahmaputra River. Water, 16(21), 3115. https://doi.org/10.3390/w16213115

782 10. Utlu M, Şimşek M, Özkaya A, Selçuk E (2026) Fifty years of geomorphology research:
783 a topic modeling analysis of global trends (1975–2025). Earth Science Informatics, 19,
784 197. https://doi.org/10.1007/s12145-026-02253-0

785 11. Bridgland D R, Westaway R (2014) Quaternary fluvial archives and landscape
786 evolution: a global synthesis. Proceedings of the Geologists Association, 125, 600.
787 https://doi.org/10.1016/j.pgeola.2014.10.009

12. Stokes M, Cunha P P, Martins A (2012) Techniques for analysing Late Cenozoic River terrace sequences. Geomorphology, 165–166, 1–6. https://doi.org/10.1016/j.geomorph.2012.03.022

13. Rixhon G, Briant R M, Cordier S, Duval M, Jones A, Scholz D (2017) Revealing the pace of river landscape evolution during the Quaternary: Recent developments in numerical dating methods. Quaternary Science Reviews, 166, 91-113. https://doi.org/10.1016/j.quascirev.2016.08.016

14. Zupic I, Čater T (2015) Bibliometric methods in management and organization. Organizational Research Methods, 18(3), 429-472. https://doi.org/10.1177/1094428114562629

15. Donthu N, Kumar S, Mukherjee D, Pandey N, Lim W M (2021) How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, 133, 285-296. https://doi.org/10.1016/j.jbusres.2021.04.070

16. Eraslan B (2026) İklim Değişikliği ve Uzaktan Algılama Literatürünün Bibliyometrik Analizi (2021-2025): Küresel Eğilimler ve Tematik Gelişim. Geomatik, 11(2), 277-295. https://doi.org/10.29128/geomatik.1908650

17. Kara B C, Hastaoğlu K Ö (2026) Ground deformation monitoring: A bibliometric analysis of recent trends and techniques. Turkish Journal of Remote Sensing, 8, 1-27. https://doi.org/10.51489/tuzal.1754180

18. Özşahin E, Kayalı Ş, Tuncel E (2026) Türkiye Üniversitelerinin Jeomorfoloji Alanındaki Lisansüstü Tezlerinin Bibliyometrik Analizi. Jeomorfolojik Araştırmalar Dergisi, 16, 94-123. https://doi.org/10.46453/jader.1816695

19. Mongeon P, Paul-Hus A (2016) The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics, 106(1), 213-228. https://doi.org/10.1007/s11192-015-1765-5

20. Page M J, McKenzie J E, Bossuyt P M, et al (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71

21. Rethlefsen M L, Kirtley S, Waffenschmidt S, Ayala A P, Moher D, Page M J, Koffel J B (2021) PRISMA-S: an extension to the PRISMA Statement for Reporting Literature Searches in Systematic Reviews. Systematic Reviews, 10, 39. https://doi.org/10.1186/s13643-020-01542-z

22. Tranfield D, Denyer D, Smart P (2003) Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management, 14(3), 207–222. https://doi.org/10.1111/1467-8551.00375

23. Aria M, Cuccurullo C (2017) Bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

24. van Eck N J, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84(2), 523-538. https://doi.org/10.1007/s11192-009-0146-3

25. Wintle AD, Murray AS (2000) Quartz OSL: Effects of thermal treatment and their relevance to laboratory dating procedures. Radiation Measurements, 32, 387-400. https://doi.org/10.1016/S1350-4487(00)00057-3

26. Wintle AD, Murray AS (2006) A review of quartz optically stimulated luminescence characteristics and their relevance in single-aliquot regeneration dating protocols. Radiation Measurements, 41 (4), 369-391. https://doi.org/10.1016/j.radmeas.2005.11.001

27. Prescott J R, Hutton JT (1994) Cosmic ray contributions to dose rates for luminescence and ESR dating: Large depths and long-term time variations. Radiation Measurements, 23, 2-3, 497-500. https://doi.org/10.1016/1350-4487(94)90086-8

838 28. Lal D (1991) Cosmic ray labeling of erosion surfaces: in situ nuclide production rates
839 and erosion models. Earth and Planetary Science Letters, 104, 2-4, 424-439.
840 https://doi.org/10.1016/0012-821X(91)90220-C

841 29. Anderson R S, Repka J L, Dick G S (1996) Explicit treatment of inheritance in dating
842 depositional surfaces using in situ 10Be and 26Al. Geology, 24(1), 47–51.
843 https://doi.org/10.1130/0091-7613(1996)024<0047:ETOIID>2.3.CO;2

844 30. Bridgland D R (2000) River terrace systems in North-West Europe an archive of
845 environmental change, uplift and early human occupation. Quaternary Science Reviews,
846 19, 1293-1303. https://doi.org/10.1016/S0277-3791(99)00095-5

847 31. Vandenberghe J (2003) Climate forcing of fluvial system development: An evolution of
848 ideas. Quaternary Science Reviews, 22, 2053-2060. https://doi.org/10.1016/S0277-
849 3791(03)00213-0

850 32. Vandenberghe J (2008) The fluvial cycle at cold–warm–cold transitions in lowland
851 regions: A refinement of theory. Geomorphology, 98, 3-4, 275-284.
852 https://doi.org/10.1016/j.geomorph.2006.12.030

853 33. Tapponnier P, Zhiqin X, Roger F, Meyer B, Arnaud N, Wittlinger G, Jingsui Y (2001)
854 Oblique Stepwise Rise and Growth of the Tibet Plateau. Science, 294(5547), 1671–1677.
855 https://doi.org/10.1126/science.105978

856 34. Molnar P, England P, Martinod J (1993) Mantle dynamics, uplift of the Tibetan Plateau,
857 and the Indian Monsoon. Reviews of Geophysics, 31(4), 357–396.
858 https://doi.org/10.1029/93RG02030

859 35. Callon M, Courtial JP, Turner WA, Bauin S (1983) From translations to problematic
860 networks: An introduction to co-word analysis. Social Science Information 22(2):191–235.
861 https://doi.org/10.1177/053901883022002003

862 36. Stott T (2010) Fluvial geomorphology. Progress in Physical Geography Earth and
863 Environment, 34(2), 221. https://doi.org/10.1177/0309133309357284

864 37. Ramsey CB, Dee M, Lee S, Nakagawa T, Staff RA (2010) Developments in the
865 Calibration and Modeling of Radiocarbon Dates. Radiocarbon, 52 (3): 953-961.
866 https://doi.org/10.1017/S0033822200046063

867 38. Rittenour TM (2008) Luminescence dating of fluvial deposits: applications to
868 geomorphic, palaeoseismic and archaeological research. Boreas, 37: 613-635.
869 https://doi.org/10.1111/j.1502-3885.2008.00056.x

870 39. Wallinga J (2002) Optically stimulated luminescence dating of fluvial deposits: a
871 review. Boreas, 31(4), 303. https://doi.org/10.1111/j.1502-3885.2002.tb01076.x

872 40. Duller GAT (2004) Luminescence dating of quaternary sediments: recent advances. J.
873 Quaternary Sci., 19: 183-192. https://doi.org/10.1002/jqs.809

874 41. Bishop P (2007) Long-term landscape evolution: linking tectonics and surface
875 processes. Earth Surface Processes and Landforms, 32(3), 329.
876 https://doi.org/10.1002/esp.1493

877 42. Heron D P L, Busfield M E, Chen X, Corkeron M, Davies B J, Dietrich P, Ghienne J,
878 Kettler C, Scharfenberg L, Vandyk T M, Wohlschlägl R (2022) New Perspectives on Glacial
879 Geomorphology in Earth's Deep Time Record. Frontiers in Earth Science, 10.
880 https://doi.org/10.3389/feart.2022.870359

881 43. Hugenholtz C H, Whitehead K, Brown O W, Barchyn T E, Moorman B J, LeClair A,
882 Riddell K, Hamilton T K (2013) Geomorphological mapping with a small unmanned aircraft
883 system (sUAS): Feature detection and accuracy assessment of a photogrammetrically-
884 derived digital terrain model. Geomorphology, 194, 16.
885 https://doi.org/10.1016/j.geomorph.2013.03.023

886 44. Westaway R, Guillou H, Yurtmen S, Beck A, Bridgland D, Demir T, Scaillet S,
887 Rowbotham G (2006) Late Cenozoic uplift of western Turkey: Improved dating of the Kula
888 Quaternary volcanic field and numerical modelling of the Gediz River terrace staircase.
889 Global and Planetary Change, 51, 131-171.
890 https://doi.org/10.1016/j.gloplacha.2006.02.001

891 45. Bridgland D R, Demir T, Seyrek A, Pringle M, Westaway R, Beck A R, Rowbotham G,
892 Yurtmen S (2007) Dating Quaternary volcanism and incision by the River Tigris at
893 Diyarbakır, southeast Turkey. Journal of Quaternary Science, 22 (4), 387-393.
894 https://doi.org/10.1002/jqs.1074

895 46. Demir T, Westaway R, Bridgland D, Seyrek A (2007) Terrace staircases of the River
896 Euphrates in southeast Turkey, northern Syria and western Iraq: Evidence for regional
897 surface uplift. Quaternary Science Reviews, 26, 2844-2863.
898 https://doi.org/10.1016/j.quascirev.2007.07.019

899 47. Demir T, Seyrek A, Westaway R, Bridgland D, Beck A (2008) Late cenozoic surface
900 uplift revealed by incision by the River Euphrates at Birecik, southeast Turkey. Quaternary
901 International, 186, 132-163. https://doi.org/10.1016/j.quaint.2007.08.010

902 48. Westaway R, Guillou H, Seyrek A, Demir T, Bridgland D, Scaillet S, Beck A (2009)
903 Late Cenozoic surface uplift, basaltic volcanism, and incision by the River Tigris around
904 Diyarbakır, SE Turkey. Int. Journal Earth Science (Geol Rundsch), 98: 601–625.
905 https://doi.org/10.1007/s00531-007-0266-z

906 49. Demir T, Seyrek A, Guillou H, Scaillet S, Westaway R, Bridgland D (2009) Preservation
907 by basalt of a staircase of latest pliocene terraces of the River Murat in eastern Turkey:
908 Evidence for rapid uplift of the eastern Anatolian plateau. Global and Planetary Change,
909 68, 254-269. https://doi.org/10.1016/j.gloplacha.2009.02.008

910 50. Doğan U (2011) Climate-controlled river terrace formation in the Kızılırmak Valley,
911 Cappadocia section, Turkey: Inferred from Ar–Ar dating of Quaternary basalts and
912 terraces stratigraphy. Geomorphology, Vol. 126 (1), 66–81.
913 https://doi.org/10.1016/j.geomorph.2010.10.028

914 51. Yıldırım C, Schildgen T F, Echtler H, Melnick D, Bookhagen B, Çiner A, Niedermann
915 S, Merchel S, Martschini M, Steier P, Strecker M R (2013) Tectonic implications of fluvial
916 incision and pediment deformation at the northern margin of the Central Anatolian plateau
917 based on multiple cosmogenic nuclides. Tectonics, 32: 1107-1120.
918 https://doi.org/10.1002/tect.20066

919 52. Kent E J (2015) The relationship between active faulting and fluvial geomorphology: A
920 case study in the Gediz Graben, Turkey. University of Plymouth, Earth and Environmental
921 Science Faculty of Science and the Environment, Doktor of Philosophy, UK.

922 53. Çiner A, Doğan U, Yıldırım C, Akçar N, Ivy-Ochs S, Alfimov V et al (2015) Quaternary
923 uplift rates of the Central Anatolian Plateau, Turkey: insights from cosmogenic isochron-
924 burial nuclide dating of the Kızılırmak River terraces. Quaternary Science Reviews, 107,
925 81–97. https://doi.org/10.1016/j.quascirev.2014.10.007

926 54. Altın T B, Altın B N, Öztürk M Z (2017) Climatic and tectonic effects on terrace
927 formation during the Late Quaternary in the Upper Yesilırmak Valley, northern Turkey.
928 Geogr. Fis. Dinam. Quat., 40. https://doi.org/10.4461/GFDQ.2017.40.9

929 55. Maddy D, Veldkamp A, Demir T, van Gorp W V, Wijbrans J R, Hinsbergen D J J,
930 Dekkers M J, Schreve D, Schoorl J M, Scaife R, Stemerdink C, Schriek T, Bridgland D R,
931 Aytaç A S (2017) The Gediz River fluvial archive: A benchmark for Quaternary research
932 in western Anatolia. Quaternary Science Reviews, 166, 289-306.
933 https://doi.org/10.1016/j.quascirev.2016.07.031

934 56. Berndt C, Yıldırım C, Çiner A, Strecker M R, Ertunç G, Sarıkaya M A, Özcan O, Öztürk
935 T, Kıyak NG (2018) Quaternary uplift of the northern margin of the central Anatolian
936 Plateau: New OSL dates of fluvial and delta-terrace deposits of the Kızılırmak River, Black
937 Sea Coast, Turkey. Quaternary Science Reviews, 201, 446-469.
938 https://doi.org/10.1016/j.quascirev.2018.10.029

939 57. Avşin N, Vandenberghe J, Balen VR, Kıyak NG, Öztürk T (2019) Tectonic and climatic
940 controls on Quaternary fluvial processes and river terrace formation in a Mediterranean
941 setting, the Göksu River, Southern Turkey. Quaternary Research, 91 (2), 533-547.
942 https://doi.org/10.1017/qua.2018.129

943 58. Erturaç M K, Şahiner E, Zabcı C, Okur H, Polymeris GS, Meriç N, İkiel C (2019) Fluvial
944 response to rising levels of the Black Sea and to climate changes during the Holocene,
945 luminescence geochronology of the Sakarya terraces. The Holocene, 1-12.
946 https://doi.org/10.1177/0959683619831428

947 59. Doğan U, Şenkul Ç (2020) When did the drainage system of the Kızılırmak River
948 form in Cappadocia (Anatolia, Turkey)? A revised geological and geomorphological
949 stratigraphy. Turkish Journal of Earth Sciences, 29, 1-14. https://doi.org/10.3906/yer-
950 2002-17

951 60. Maddy D, Veldkamp A, Demir T, Aytaç A S, Schoorl JM, Scaife R, Boomer I,
952 Stemerdink C, Schriek T, Aksay S, Lievens C (2020) Early Pleistocene River terraces of
953 the Gediz River, Turkey, the role of faulting, fracturing, volcanism and travertines in their
954 genesis. Geomorphology, Vol. 358. https://doi.org/10.1016/j.geomorph.2020.107102

955 61. McClain K P, Yıldırım C, Çiner A, Sahin S, Sarıkaya M A, Özcan O, Kıyak N G, Öztürk
956 T (2020) Quaternary rock uplift rates and their implications for the western flank of the
957 North Anatolian Fault restraining bend, inferences from fluvial terrace ages. Tectonics, 39
958 (10), 1-22. https://doi.org/10.1029/2019TC005993

959 62. Avşin N, Erturaç M K, Şahiner E, Demir T (2021) The Quaternary climatic and tectonic
960 development of the Murat River Valley (Muş Basin, Eastern Turkey) as recorded by fluvial
961 deposits dated by Optically Stimulated Luminescence. Quaternary, 4, 29.
962 https://doi.org/10.3390/quat4030029

963 63. Hubert-Ferrari A, Drab L, Woerd J V D, Benedetti L, Van Campenhout J V (2021)
964 Cosmogenic data about offset uplifted river terraces and erosion rates: Implication
965 regarding the central north Anatolian fault and the central Pontides. Mediterranean
966 Geoscience Reviews, 3 (1), pp. 129-157. https://doi.org/10.1007/s42990-021-00057-6

967 64. McClain K P, Yıldırım C, Çiner A, Sarıkaya M A, Özcan O, Görüm T, Köse O, Şahin
968 S, Kıyak N G, Öztürk T (2021) River, alluvial fan and landslide interactions in a tributary
969 junction setting: Implications for tectonic controls on Quaternary fluvial landscape
970 development (Central Anatolian Plateau Northern Margin, Turkey). Geomorphology, 376,
971 107567. https://doi.org/10.1016/j.geomorph.2020.107567

972 65. Erturaç M K (2021) Late Pleistocene-Holocene Characteristics of the North Anatolian
973 Fault at Adapazarı Basin: Evidences from the Age and Geometry of the Fluvial Terrace
974 Staircases. Turkish Journal of Earth Sciences, Vol. 30, No. 1, s. 93- 115.

975 66. Karakoca E, Uncu L, Sarıkaya M A, Şahiner E, Köse O (2021) Dating of fluvial terrace
976 systems in the middle Sakarya valley using OSL method, Sakarya River, Bilecik, Turkey.
977 British Society for Geomorphology Conference 2021, 13-15th September.

978 67. Karakoca E (2022) Fluvial geomorphology of middle Sakarya River between Inhisar-
979 Osmaneli. PhD. Thesis. Bilecik Seyh Edebali University, Institute of Social Sciences,
980 Bilecik.

981 68. Karakoca E, Uncu L, Sarıkaya M A, Şahiner E, Köse O (2025) Geomorphology and
982 chronology of Late Quaternary terrace staircases of the Sakarya River, northwest Türkiye.
983 Journal of Quaternary Science, 40(3), 386-399. https://doi.org/10.1002/jqs.3695

984 69. Briant R M, Bridgland D R, Cordier S, Rixhon G, Balen R T van (2019) A celebration
985 of the twentieth anniversary of the Fluvial Archives Group (FLAG). Quaternary Research,
986 91(2), 453. https://doi.org/10.1017/qua.2018.138

987 70. Rashidi Koochi Z, Büdel C, Walk J, Fuchs M, Torabi M, Karimi A, Baumhauer R, Stauch
988 G (2025) Late Quaternary geomorphological processes and landscape evolution in the
989 Khur Basin, central Iran. E&G Quaternary Science Journal, 74, 193–212,
990 https://doi.org/10.5194/egqsj-74-193-2025

991 71. Gallen S F, Fernández-Blanco D (2021) A New Data-Driven Bayesian Inversion of
992 Fluvial Topography Clarifies the Tectonic History of the Corinth Rift and Reveals a Channel
993 Steepness Threshold. Journal of Geophysical Research Earth Surface, 126(3).
994 https://doi.org/10.1029/2020jf005651